ESE 440: Senior Design

Temperature Controller

Seong Kang
Rafal Piersiak

with Professor Westerfeld

Abstract

This design report is aimed to log the process of designing and implementing a temperature controller system for laser emitting diodes. As the senior design project of Seong Kang and Rafal Piersiak, advised by Professor Westerfeld, this system will use a thermoelectric cooler and the Peltier effect to maintain a constant temperature on the diode. The report aims to discuss the background, goals, the design (including its constraints and implementation), and the results gathered from the completion of the system. Along with the design details of the system, the report also includes logistics details on how the project had been tasked and assigned in order to make the workload be effective and educational for both members.

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Section 1: Goals and Impacts

The temperature controller detailed in this report is used mostly in a lab environment. Its primary use is at a laboratory setting where the diodes undergo endurance testing. Throughout the testing, constant temperature is necessary in order to get an accurate current vs. light-intensity relationship. Endurance testing also implies that the system, along with the diode, will function correctly for a long period of time.

So the primary use of the temperature controller is to assist Professor Westerfeld's research in laser emitting diodes. Thus the system has certain indirect effects that can impact society. The ongoing research and production of powerful laser emitting diodes has various applications in gas detection, military self-defense, medical and industrial procedures. So by assisting the research of laser diodes, this system has overarching effects that are not immediately visible. In addition, the basic model of this temperature controller can be modified for applications other than laser diode research. This expands the potential impact of this system to be more consumer-friendly.

Section 2: Background

2.1 Survey

This system was developed to assist Professor Westerfeld in his laser diode research. A temperature controller is necessary in order to get accurate results during endurance testing. Endurance testing means the system is required to do several things: consider the potential thermal load of up to 10 W; maintain a user-specified temperature anywhere from 15°C and 60°C; and maintain this temperature for long hours. And because it is mainly developed for lab use, there were no power restraints to consider for the temperature controller; from a design perspective, there's practically infinite power available to the temperature controller.

2.2 Project Planning

There were several components that needed further researching in order to develop the temperature controller. The correct thermoelectric cooler needed to be selected based on the design constraints. This also meant some basic overview of the Peltier effect was needed. Some of the other major components of the system are the PID controller, the microcontroller, the TEC (Thermoelectric Cooler), the TEC driver, and the LCD (Liquid Crystal Display).

The majority of the initial design phase consists of researching these major parts for the project. In order to maximize productivity, the group split up the researching responsibility based on the major components needed. Before researching, some basic knowledge of electronic circuits and components were essential for researching because we had to know what we were looking for. With basic knowledge, it is possible to summarize the system in a high-level block diagram. This diagram will allow for the researching of components to be divided evenly amongst the group members. Since a microcontroller will be used to control the whole system, there is a need for an extensive knowledge of embedded systems. Through the coursework offered in ESE 380 and ESE 381, we were able to get valuable experience working with microcontrollers in the ATmega family. This project, however, will require an extensive knowledge of microcontrollers and will challenge us to acquire more knowledge in feedback loops, pulse width modulation, finite state machines, SPI, and bus-interface. We seek to acquire this knowledge through experience of working on the project, as well as referencing textbooks and websites which explain these concepts.

With regards to the TEC, neither of us has any experience working with them. This means a lot of time has to be dedicated in researching how a TEC works and its relative significance in connection to an electronic circuit. The requirements of the TEC are based on the temperature range in which our diode will be operating in. As previously explained, the TEC should handle up to 10 W within a temperature range of 15°C and 60°C. These specifications for the TEC may be found in their corresponding datasheets. This means we will be researching a lot of datasheets of in order to obtain the necessary information and pick the right TEC.

Datasheets are a primary source that we will be referencing from often. They are essential in retrieving the specifications that we will be looking for. Many Atmel datasheets also provide example codes, flags, and control registers that will assist us in programming our embedded system. Being a primary source directly from the manufacturer themselves, these datasheets should have accurate information that we can extract in order to apply it to our controller. Most importantly however, based off of our academic history, we believe the best way to acquire new knowledge is through hands-on learning. This project will offer us plenty of learning experience as it will expose many problems that were previously unforeseen and how they can be resolved step by step.

Section 3: System Design

3.1 - Design Constraints

The main design constraints facing the system are technical. There are minimal ethical, social, and environmental constraints since our system is used primarily for research and technical applications. The other major constraint is financial. The ESE/ECE department is able to compensate up to $230 spent on the project. So ideally, we should try to maintain our project costs to be under that sum. With these two major constraints considered, technical and financial, we are able to observe each component of the project along these limitations.

PID Controller - This is a basic control loop feedback system that may be implemented with hardware using amplifiers. It may also be implemented through software. We need to make a choice between opting to go with the hardware or software implementation. The advantages and disadvantages of these two types of implementations need to be considered before picking one for our design.

Microcontroller - The microcontroller is tasked with handling most of the functionalities that will be supported by the system. It is one of the central components. Once this part is chosen, much of the other components of the circuit must be checked for its compatibility based on the microcontroller. First and foremost, the microcontroller needs to have enough ports to support the number of peripherals we will be using. It also needs to have enough memory to process the amount of computations the system needs. Other considerations for the microcontroller include its usability. Is it difficult to code? If the microcontroller supports C, it will be much easier to code our functions. Does it support PWM, a bus and SPI interface? We must also consider the added restriction from our financial constraint. Ideally, our microcontroller should meet the bare minimum requirements while not draining too much of our financial resources.

TEC – This device uses the Peltier effect to heat and cool objects. The amount of heating and cooling is controlled by the current going through the device. The major characteristics of a TEC are power rating and ΔT (Maximum Change in Temperature). Picking the correct parameters is critical to the functionality of the entire system. Without a properly selected TEC, the temperature controller will not be stable and will have a very difficult time to produce efficient changes in temperature.

TEC Driver - This driver is essentially an H-Bridge that will alter the direction of the current depending on whether the TEC needs to be hotter or colder. The main issue here is whether or not the TEC driver will be able to handle the power load that the TEC needs in order to operate. The TEC can take up to 4 amps of current to alter the temperature as necessary. Therefore, we must select the TEC driver to handle up to that same amount of current.

Temperature Sensor – The primary concern for the temperature sensor is its accuracy. This system requires an accuracy of 1°C over the entire range of applicable temperatures. To meet this goal, a temperature of at least 1°C accuracy is necessary. The thermometer also needs to support a certain resolution, which brings us to the discussion between digital and analog temperature sensors. Both have their pros and cons; they will be discussed heavily in this report.

LCD – The LCD needs to provide enough information to the user, while maintaining a simple and sleek graphical interface. The LCD will only display temperature readings and setting. It will also show various messages signifying mode changes and error messages. The LCD can also be accompanied with a backlight, which will be considered in the design as well.

Audio Alarm – A piezo electric buzzer can be used to bring attention to significant events regarding the operation and setup of the temperature controller. In this design, the alarm will be used to alert the user to unsafe conditions regarding thermal runaway and circuit malfunction. It can also be used to as a queuing sound to tell the user that a setting has been set.

LEDs – These devices will be used as indicators to actions that deserve special attention. There is not much design involved with LEDs other than picking a proper color and making sure that the LED has a well selected current-limiting resistor.

Pushbuttons – Producing changes in a system requires the use of stimuli to push it to different states. This system will employ pushbuttons as the primary way for data entry. The major issue with pushbuttons is problems with bouncing signals that need to be rectified with a hardware or software solution. Hardware debouncing is more robust, but requires extra hardware and space. Software debouncing requires no additional hardware, but can cause erroneous results if the software is not configured properly.

Power Switch – Having a power switch on hand will allow the user to shut down the entire system with one press on a button. The switch may be expensive, because it will have to withstand at least four amps of current.

3.2 Designs Considered

For the PID controller, there are basically two options: hardware or software. Implementing it in hardware would require a series of analog calculations to choose the correct resistors, capacitors, and amplifiers. Its advantage is that the effects of the feedback loop would be almost instantaneous since it is all composed of simple analog parts. Software implementation would be simpler in comparison. Making alterations to the parameters of the PID controller will be much easier since its corresponding variables just have to be changed within the code. But we do have to take in the consideration the delay we will get from the microcontroller as it calculates the changed variables.

The choice of microcontrollers to use was easily narrowed down to microcontrollers from Atmel. This was due to the fact that we have the most experience in working with microcontrollers from Atmel's ATmega family. ESE 380 was taught with the ATmega16, while ESE 381 was taught with the ATmega128. So due to our familiarity with the ATmega microcontrollers, we decided to choose the best fitting microcontroller from the ATmega family. The datasheets of various ATmega microcontrollers were used to pick which controller would fit the minimum requirements and be the most financially efficient.

TEC's come in two flavors: low voltage and high power output, or high voltage and low current. Picking the right flavor is the primary deciding factor. It is usually easier to use high voltage, low current systems because most power supplies can source higher voltages rather than higher currents. The TEC we are using is high voltage, low current.

The second factor in selecting a TEC is its power rating. Without a properly selected power rating for the TEC, the system will struggle to alter the temperature of the object. It may become very sluggish and take a long time to produce a significant change it temperature. The system may even become unresponsive and fail completely. It is also important to choose a TEC that will provide the necessary power dissipation without maxing out the TEC. Driving the TEC at its limit puts strain on the TEC and can even be less efficient then driving at a lower current. Therefore having a ratio of roughly 0.5 or less in terms of the power dissipation with respect to the maximum power output of the TEC will provide decent results and will require less energy.

As for the TEC driver, the main concern is its ability to allow upwards of 4 A through the driver. However, to compensate for the overhead, it may be safer to get an H-bridge rated for current higher than 4 A. There are two general implementations of an H-bridge. The first implementation utilizes four independent Power MOSEFETs that are pulsed to provide a directional current. This method allows for greater durability and better heat dissipation. The major issue with this implementation is the need to characterize the H-bridge to provide discrete levels of current. This becomes increasingly difficult when you have to configure four MOSFET's which all have their own intrinsic impedances. We also need to consider that we need two PMOS and two NMOS, which will complicate matters even further. Implementing an H-bridge this way is more beneficial when variable currents are not involved, such as driving a motor at one specific level.

There are too many reasons not to use four independent POWER MOSFETs in our design. A better solution is to purchase an integrated H-bridge that is configured for pulse width modulation (PWM). This avoids the need to test all the MOSFETs for currents at every discrete level. Although it may be easier to use at first glance, there are a number of difficulties involved, such as understanding how the part works and writing software that interfaces with the part.

Power dissipation will be another major issue that will need to be addressed. This part will drive large currents at times, which means a heat sink will be needed. On possible solution to the power dissipation problem is to attach the part to main metal assembly, which has a significant metal surface area.

Without a temperature sensor, our system would not know how to react. Two types of temperatures sensors will considered for this design. The first type is an analog temperature sensor with a linear output. These are very easy to use and don't require any software to read a value from the sensor. They are also very fast and perform thousands of readings every second. The main reason this will not work is that to get a resolution of 0.1°C with the ATmega's 10-bit ADC and an analog temperature sensor, would require a 1.024V reference. This would amount to 1mV per bit of change, which corresponds to a change of 0.1°C per bit. Building the system in this manner provides the desired solution, but it comes with a hefty expense. A change of 0.1°C corresponds to a 1mV change. This severely limits the robustness of the temperature sensor and the system as a whole. Such a small sensitivity would cause oscillations in temperature of a few tenths of a degree just do to the parts and outside noise.

A better solution is to use a 12-bit external ADC with a linear analog temperature sensor. This gives a more robust system and dampens the effects of noise. The sampling speed of the sensor is also very fast in this configuration as well. The issue now is that you need additional hardware and software to read the temperature.

The digital solution to this problem can be implemented with a digital thermometer that provides at least 0.1°C resolution. A 12-bit thermometer will provide 0.0625°C resolution, which is more than enough for this system. The big problem with digital sensors is that they are very slow. A typical 12-bit conversion can take 750ms; this doesn't include the time required to extract the data from the temperature sensor. These devices also require a lot of software just to read the register that holds the converted temperature. Although they don't need any additional hardware, they are very slow and software intensive. Not getting enough temperature readings may make the system unstable because it can't react quick enough to counter quick changes in temperature.

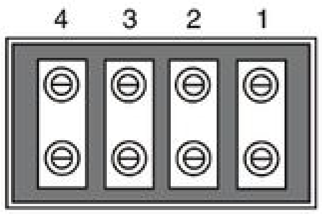
LCDs are great ways to display information to a user. Our system will use an LCD with SPI (Serial-Peripheral-Interface). We find that this method of data transfer is easy to use and implement. It will also feature a backlight, which should aid in the display of the text on the LCD. Other than choosing a manufacturer, there isn't much design consideration for the LCD other than cost. The cost of the LCD will be kept at a minimum.

Considerations involving the audio alarm are minimal. The alarm will be driven by a DC voltage. These types of buzzers have an internal resonator that is triggered when power is applied. AC buzzers require an external AC source to creating an alarming sound. The alarm will also be small to conserve on space. Many buzzers have decibel ratings on their datasheets. A good alarm will have a rating of 85dB, which is the equivalent of city traffic inside a car.

The pushbuttons in the system will be large enough to press easily with one finger. They will be low profile to minimize accidental presses. The make and bounce times of the pushbuttons will not be considered until the actual building of the design. Either hardware debouncing or software debouncing will be utilized to limit accidental triggers. The design will implement a NAND gate coupled with a flip-flop to trigger an interrupt to signify that a function wants to be called.

3.3 Final Design

A thermoelectric cooler has been provided to us by Professor Westerfeld. The model name of the TEC is MPA075-12. Upon research of this TEC, we were able to find some specifications regarding this particular model. It has cooling capacities of up to20 W. It has the following power connections:



Position	Description
1	TEC +
2	TEC -
3	Fans +
4	Fans -

Figure 1- Power Connector of MPA075-12 (www.lairdtech.com)

As well as the following specifications:

Model No.	Qmax (BTU/hr. / watts)	Nom. Input (VDC / A)	Max Input (VDC / A)	Wt. (lbs. / kg)
MPA075-12	73 / 21	12 / 3.2	14.4 / 3.9	1.3 / 0.06

Figure 2-Some electrical characteristics of MPA075-12 (www.lairdtech.com)

The most logical solution for our PID controller was to implement with software within the microcontroller. If the controller was hardware implemented, it would require us to constantly switch out resistors, capacitors, or amplifiers in order to change our parameters. This would significantly hinder our development. And although it has an advantage of being nearly instantaneous, the TEC doesn't need its parameters to be instantaneously changed. The microcontroller works at a fast enough frequency where the delay to process the new variables will have little to no effect on the overall functionality of the temperature controller.

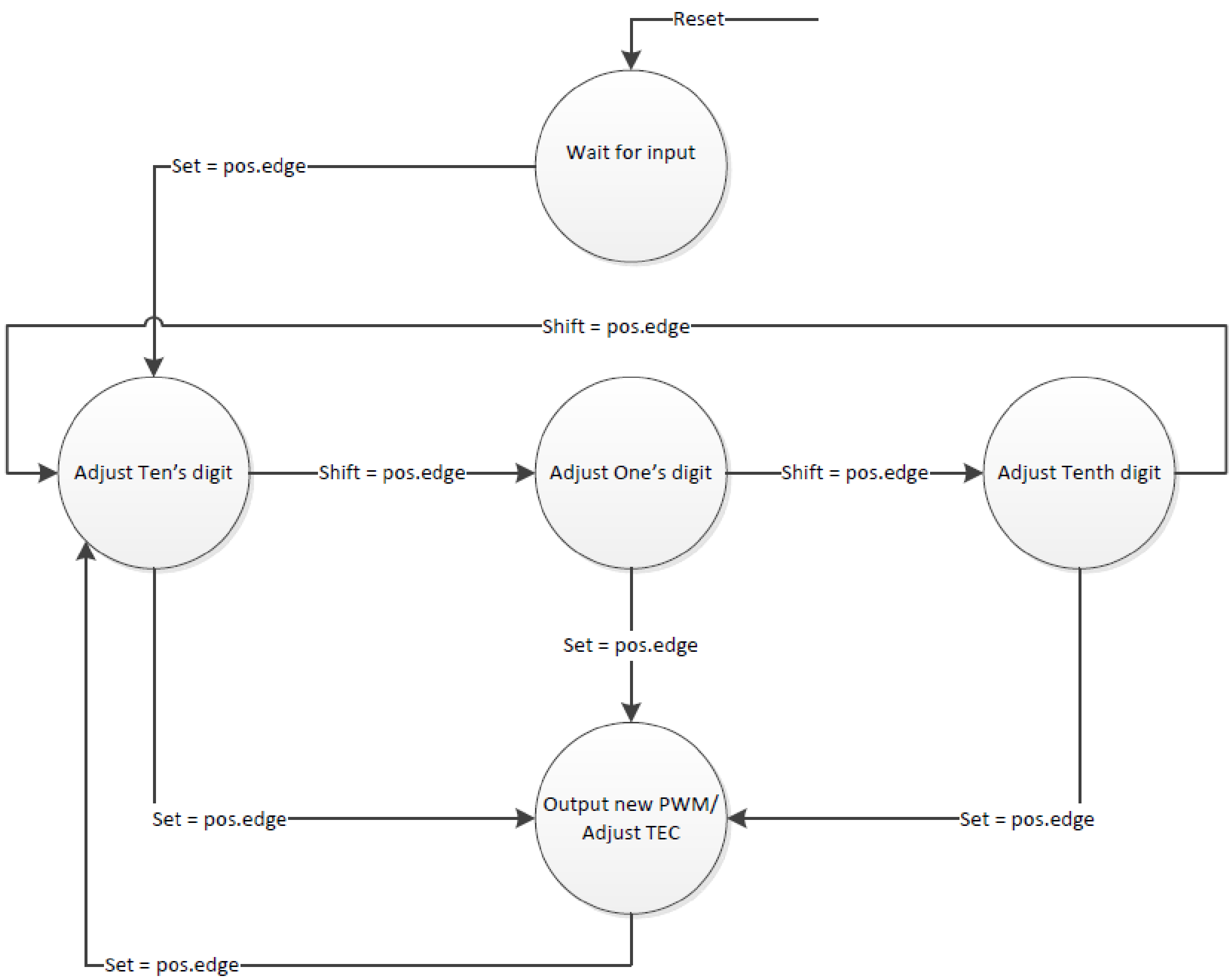


Figure 3 - FSM diagram of Temperature Controller

There were two H-bridge integrated chips that fit met our current requirements. One chip is the E-L6201PSTR. This chip can be bought for $8.35 per unit from Digikey. The other option is the MC33887. This chip can be bought for $5.71 per unit from Mouser Electronics. Both of these chips are MOSFET based H-bridge IC that are rated for a maximum current of 5 A. They are both surface mount chips. Narrowed down to just two options, we can easily compare the two chips in further detail and see whether the cheaper option can satisfy our system. There is a third chip, the MAX1969, which is developed to be used with TECs. But this chip costs nearly $27 per unit; so this chip will make it easier to develop the TEC driver but it may be too expensive of an option.

We want to minimize the size of our microcontroller and maximize our efficiency. We wish to start our design with the ATmega32. There are other options out there with bigger memory but we will seek to program our system with the most efficient software so we can minimize the physical size of our hardware. It will be a bigger challenge to code with the ATmega32 but the potential benefits may be worth it. The ATmega32 has an SPI and a bus interface, as well as an analog-to-digital converter. It also has several external interrupt ports in addition to an internal counter that can be used to trigger interrupt subroutines and pulse-width-modulation. From Atmel's official website, the following parameters can be found for the ATmega32: 32 Kbytes of Flash Memory, 40 Pins, 16 MHz max operating frequency, 32 Max I/O pins, 3 external interrupts, 1 SPI, 8 ADC channels each with 10-bit resolution, and 1024 Bytes of EEPROM. As the design progresses, the ATmega may be taken out and swapped with an ATtiny. Using an ATtiny is a cheaper option and should be perfect for this application. The ATmega provides a large number of ports the will go unused so switching to a smaller microcontroller is the long term goal.

Because we don't know the time constraints for the system yet, we will go forward with a digital thermometer that can provide 12-bit resolution. A good example is the DS1626, which has a 750ms conversion time and costs $4.54. We will also purchase the MAX1377ATP+ 12-bit ADC, an LM35 temperature sensor and a REF198 (4.096V) reference to try and implement an analog implementation of the temperature reading. In case the digital temperature sensor can't meet the speed requirements, we will have the analog version ready to go.

The following flow chart shows how the feedback loop will work. The laser temperature is read near the laser using a temperature sensor. This data is fed to the PID Controller, along with the binary representation of a set point temperature. The PID Controller will analyze these inputs and decide how to implement the desired temperature change. The PID controller will finally modulate a pulse that is fed to the H-Bridge. The H-Bridge will source a current to the TEC to create a difference in temperature. This process will repeat once again when the temperature sensor reads another value and gives it to the PID Controller.

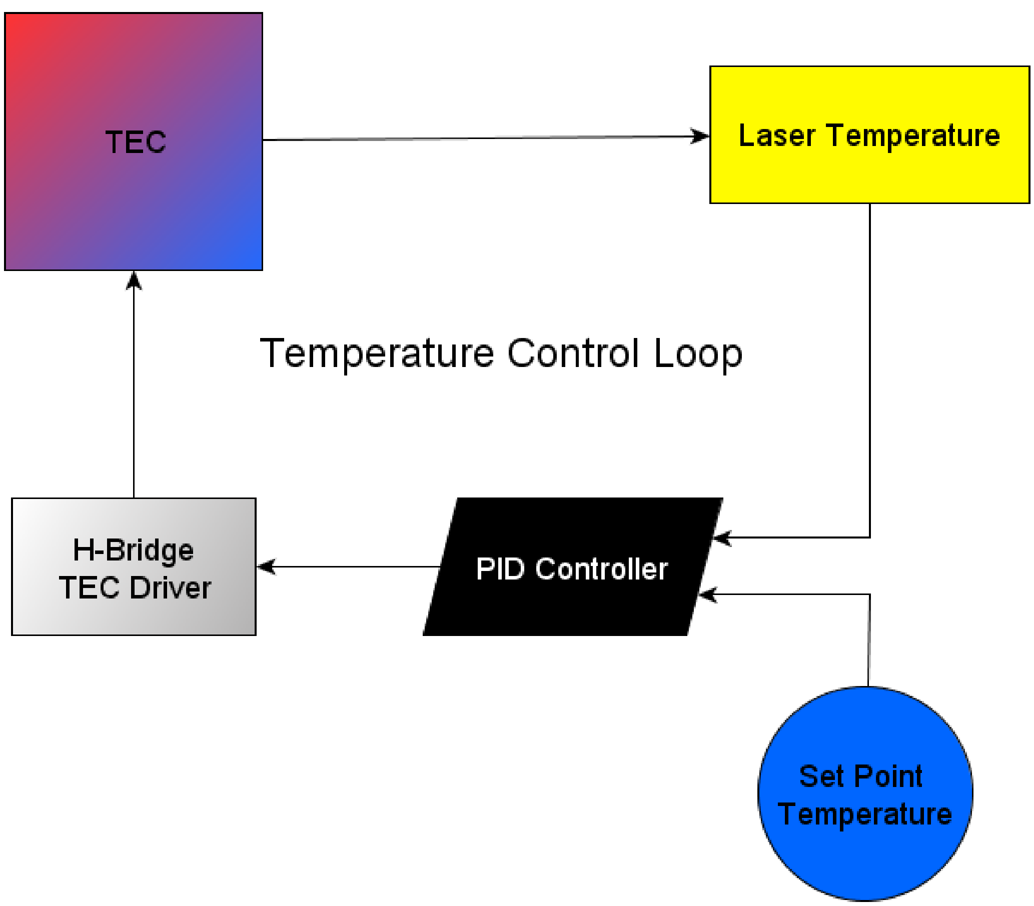


Figure 4 - Temperature Control Loop

Our team has become acquainted with the Electronic Assembly DOGM LCD display during our ESE380 and ESE381 courses. We plan to use the EA DOGM162W-A LCD in conjunction with the EALED55X31-A amber backlight. We have all of the documentation and software required to write to the LCD, which is why we chose this part.

Figure 5 - LCD Data Arrangement

The alarm will be purchased from Mallory, which makes small DC piezo electric buzzers. The PK-12N40PQ will be used in the system to provide sound indicators for various functions and errors. It is rated for 83dB, which is loud enough to alert the operator of any issues.

Choosing the LEDs is not considered in the initial design. Our team has our own supply of LEDs that we plan to use in the project. LEDs are cheap and don't have much of an impact on the cost of the system. They will be diffuse LEDs that act as indicators.

The pushbuttons will be square shaped and have a yellow cap for the button. We will purchase four 320.01E11YEL pushbuttons to serve as stimuli for the system. The pushbuttons will be connected to the CD74HC20 4-input NAND gate to create and unencoded linear key array. The output will be connected to a flip-flop to store the request for interrupt.

In order to shutdown the system, the user will have the option of pressing a switch rather than pulling out the power cord, or disconnecting the power supply. We will use a rocker type switch to minimize accidental shutoff.

Once the major components of the system are implemented, we will insert a fuse to prevent excess current from damaging our parts. We don't yet know how much current the TEC will need, so the proper fuse rating is unknown as of now.

To minimize the use of several power supplies, the system may use a 5V voltage regulator to power all of the components other than the fan, TEC, and possibly the audio alarm. This will simplify the setup of the system and make it easier to use when only a 12V power source is required.

The following table is the list parts we have compiled so far:

Part Name	Model Number	Sales ID	Price ($)	Quantity	Total ($)
ATmega32 (microcontroller)	ATMEGA32A-PU	ATMEGA32A-PU-ND	5.36	1	5.36
L6201 (H-Bridge)	E-L6201PSTR	497-4568-1-ND	8.30	1	8.30
MC33887 (H-Bridge)	MC33887PNBR2	MC33887PNBR2-ND	5.71	1	5.71
MAX1969 (TEC Driver)	MAX1969EUI+	MAX1969EUI+-ND	25.54	1	25.54
LM35DMX (Temp. Sensor)	LM35DMX	LM35DMX-ND	2.07	1	2.07
LM35DZ (Temp. Sensor)	LM35DZ	LM35DZ-ND	1.71	1	1.71
MAX31723MUA+ (Temp. Sensor)	MAX31723MUA+	MAX31723MUA+T	$3.63	1	$3.63
DS1626 (Temp. Sensor)	DS1626	DS1626U+	$4.54	1	$4.54
MAX1377ATP+ (12-Bit ADC)	MAX1377ATP+	MAX1377ATP+	$2.56	1	$2.56
REF198 (4.096V Ref)	REF198GS	REF198GS	$2.59	1	$2.59
PKM24SPH3805 (Buzzer)	PKM24SPH3805	PKM24SPH3805	1.94	1	1.94
PK-12N40PQ (Buzzer)	PK-12N40PQ	458-1066-ND	2.43	1	2.43
CD74HC20 (4-in NAND)	CD74HC20E	CD74HC20M	0.10	1	0.10
SN74HC14 (Schmitt invert)	SN74HC14N	SN74HC14N	0.10	4	0.4
SN74HC74 (Dual D-FF)	SN74HC74N	SN74HC74N	0.10	1	0.1
DOGM162W-A (LCD Display)	DOGM162W-A	790-EADOGM162WA	11.41	1	11.41
EALED55X31-A (LCD Backlight)	EA LED55X31-A	790-EALED55X31A	$2.86	1	2.86
320.01E11YEL (Pushbutton)	320.01E11YEL	EG2555-ND	1.66	4	6.64
				Total ($)	$87.89

Table 1- The price and quantity represent the most ideal numbers; that is, the bare minimum in which our system needs.

The major components have been roughly compiled and described above. With this information, we can draw a very high-level block diagram of our major components. Please be aware that not all parts have been displayed in the following figure.

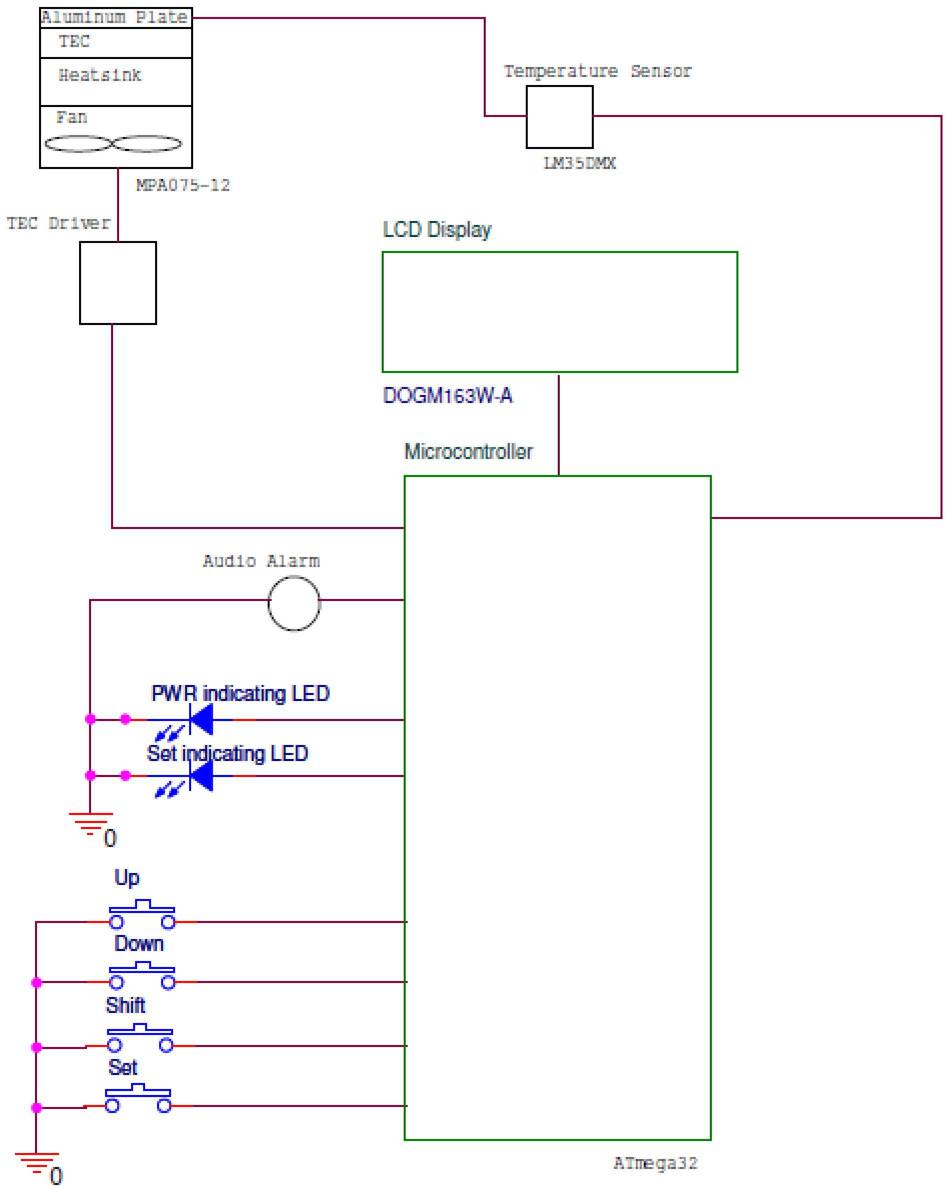


Figure 6 - A high-level block diagram showing the major components of the system

Section 4: Results and Discussions

4.1 Multi-Disciplinary Issue

Our team contains two electrical engineering majors, which provides us with a strong background in hardware. A large portion of our project requires many peripheral devices that can meet the demands of a 10 Watt laser. We have gone into a great deal of research to find good quality parts that are minimal in size and cost.

Our electrical engineering background has helped us attain a good deal of experience in software. The main portion of our project requires us to implement a software based PID controller using embedded C. Although only one of us has experience with Embedded C, we will work through this obstacle by brushing up on the language to improve our experience with the language.

Seong is also majoring in Applied Mathematics. His advanced math skills will be beneficial for calculations involving exponential growth and decay factors associated with the change in temperature over time.

Our group doesn't have problems with multidisciplinary issues. We both have a solid background to complete the hardware and software for the task. Having a computer engineer on board would probably not provide any benefit to this project.

The primary purpose of our temperature controller is to stabilize the temperature of a laser over thousands of hours. Although the time scale involved with the system is large, it must be able to handle sudden changed in ambient temperature and load power. This creates a stable environment for the laser for any length of time. This type of response has a host of applications in a variety of disciplines. It can be used in the cooling of CPU's in desktop computers to maximize clock speed. It can aid in the reporting of accurate weather parameters such as pressure, which can vary based on temperature. It would be very beneficial to lab technicians, doctors, and researchers who require stable temperature environments for blood, bacteria, and other temperature sensitive liquids and organisms. Our temperature controller can even be scaled up to control the temperature of fermentation tank for the production of alcohol. As you can see, our technology doesn't only benefit electrical engineering; it benefits a number of areas.

4.2 Professional/Ethical Issues

The temperature controller proposed by our team is a self-contained system that doesn't affect the function of other devices through emissions, such as radio signals. Our system is also considered a build-it-yourself system, which has no certification requirements from the FCC. Therefore, we don't require any licenses from the Federal Communications Commission (FCC). If we decided to sell are systems, we would be required to obtain a license from the FCC. For the most part our system only affects the temperature in a confined setting such as a laboratory or home and does not produce emissions that can be considered harmful to other devices.

Our team is built of two university students who are currently on track to receive their degrees in electrical engineering in May 2012. We are technically not "professionals" in the sense that we do not have an official degree, but we do have the experience and proper ethical training to pursue a project of this magnitude. This team is also under the supervision of an experienced professor, who will oversee the design and implementation to ensure the project follows professional and ethical standards.

The main ethical issue regarding our system is that it is not particularly environmentally friendly. Thermoelectric coolers are highly inefficient, with roughly a 5% power-to-heat conversion ratio. Running several of these devices can be costly over thousands of hours and ultimately contributes additional greenhouse gases to the atmosphere. Unfortunately, there are no other viable designs that offer a simple and cheap solution to heating and cooling a laser.

Because this system is required to work with sensitive devices, are design will have follow a liberal derating of 25%. This will ensure that any stray voltages, currents, transient spikes, and environmental disturbances will be less likely to damage or render the system inoperable. Derating the parts will also minimize the effect of part wear on the stability and endurance of the system. This design is intended for continuous use, which is why it is necessary not to design near the limits of the components.

4.3 Impact of Project on Society or Contemporary Issues

This project will immediately impact the characterization of Professor Westerfeld's high intensity mid-infrared laser. Professor Westerfeld wants to collect data on the endurance of his lasers. To perform endurance testing, you need to stabilize the temperature of the device for a long period. Our temperature controller will ensure that the temperature of the laser will be maintained at a specific set point. Holding the laser at a specific temperature over long periods guarantees that temperature variations did not affect the overall life of the laser. Testing the devices at several set points will reveal which temperature provides the longest life. The goal is to limit outside influences and maximize the life of the laser.

Other fields also require temperature controllers. Our temperature controller will be targeted towards manufactures and testing facilities, which often perform temperature-sensitive testing on their devices. Because our system is relatively cheap, any corporation can purchase hundreds of them if they wish. This will allow them to amass large amounts of data in a short time and make a faster return on their investment. Being able to provide customers with solid endurance test data can potentially sway the customer to purchase your product or service.

Some companies many not be able to afford expensive temperature control equipment. The key word for our design is low cost. Temperature controllers currently cost thousands of dollars. A testing apparatus can be well over one thousand dollars. Our temperature controller and testing apparatus will be of professional quality right out of the box for a fraction of the cost. This means that hobbyists and small businesses will have access to this system as well.

Some companies, individuals, and government agencies may skip doing various tests because they cannot afford temperature control equipment. This may put lives at risk due to hardware failure, unsafe food and drinks, contaminated medicine, and unsafe work conditions. Providing a solution to make temperature-sensitive tests inexpensive will benefit the health and safety of countless people.

It has become common to receive counterfeit parts, even from reputable distributors on occasion. A great way to test the authenticity of the part is to subject it to various cycles of heating and cooling. Most counterfeit parts are built with low quality materials, which do not perform well below or above 25°C. Testing the basic functionality of the part while it is off the board can save hours of debugging, costly re-spins, and unnecessary redesigns.

Section 5: Summary and Conclusion

The low cost temperature controller we are proposing will contain a mixture of analog and digital subcomponents that will provide stable temperature control in a predefined temperature range. It will use software techniques, hardware, and a feedback loop to provide autonomous control of the temperature. Several peripherals including an LCD and an audio alarm will be used to provide data to the user. The system will be operated with pushbuttons that will control the set point temperature.

We have compiled this report to showcase the research and planning that has been dedicated to the project so far. This report should guide us through the actual development phase where we will be able to use it as a reference to implement our design. In addition to the design component, we have also observed various non-technical issues that may arise throughout the development of this system. We have discussed the potential ethical, professional, and multi-disciplinary issues, as well as the direct and indirect impact our project may have. Our further goal is to develop a fully-functional system as described in this report, and satisfy the specifications needed for its technical and research applications.

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